2.13 DETAILED RESULTS FOR MULTIPATH AND DIFFRACTION

Based on comparison of this code with the documented design in the PD[3], *RADGUNS* simulates the multipath phenomenon accurately. Some shortfalls in independent authoritative references for methodologies were discovered. These do not necessarily indicate that problems exist with *RADGUNS*; rather, some modeling methods may not be the most common methods in use by the modeling community. Table 2.13-1 summarizes the desk checking and software testing verification results for each design element in the Multipath/Diffraction FE. One entry is listed for each of the eight design elements. The results columns contain check marks if no discrepancies were found during verification. Where discrepancies were found, the Desk Check Result column contains references (D1, D2, …) to the discrepancies listed in Table 2.13-3, while the Test Case Result column identifies the relevant test cases which explain the discrepancies.

TABLE 2.13-1. Verification Matrix for Multipath FE.

Design Element	Code Location	Desk Check Result	Test Case ID	Test Case Result
13-1: Multipath Factor	MPATH2, 35-46	Y	13-1	Y
13-2: Indirect Path Length	MPATH1, 76	Y	13-2	Y
13-3: Grazing Angle	MPATH1, 77-81	Y	13-3	Y
13-4: Phase Angle (Single-Bounce)	MPATH1, 83	Y	13-4	Y
13-5: Phase Angle (Double-Bounce)	MPATH1, 85	Y	13-5	Y
13-6: Reflection Coefficients (Land)	MPATH1, 93-95	D1, D2	13-6	13-6
13-7: Reflection Coefficients (Sea)	MPATH1, 96-107	D3	13-7	13-7
13-8: Surface Reflectivity	RGIO, 2537	D4	13-8	Y

2.13.1 Overview

In *RADGUNS* v.1.8, Functional Element 2.3 models multipath interference effects. The engagement zone for AAA systems has a smaller radius than threat systems; therefore, diffraction effects are substantially reduced and are not modeled in *RADGUNS*.

Multipath is an interference condition that usually occurs at low tracking altitudes when reflected energy is received from round-trip paths other than directly from the target. The power and direction of return of multipath signals are determined by the radar range equation, path geometry, and scattering surface properties. The radar range equation accounts for signal strength at the target and scattering points. Path geometry dictates range distances, phase shift due to path length differences, and directional transmitter and receiver gain coefficients. Scattering surface properties include surface location, orientation, and roughness factors. The amount of energy reflected from a surface element is characterized by a reflection coefficient which is a function of surface roughness, wave polarization, and vegetation.

2.13.2 Design Elements

The multipath FE incorporates eight verification design elements. These are described in detail in Section 2.3.3 of the PD[3]; a discussion of the software design is contained in Section 2.3.4. The design elements are summarized in Table 2.13-2.

TABLE 2.13-2. Multipath Design Elements.

Module	Design Element	Description
MPATH2	13-1: Multipath Factor	Compute the resultant multipath multiplier in radar range equation calculation.
MPATH1	13-2: Indirect Path Length	Compute the geometric path length of signal return via terrain reflection.
MPATH1	13-3: Grazing Angle	Compute the grazing angle of ray from radar to specular reflection point.
MPATH1	13-4: Phase Angle (Single-Bounce)	Compute the phase angle shift of indirect wave return relative to direct wave return when indirect path includes a specular reflection in only one direction.
MPATH1	13-5: Phase Angle (Double-Bounce)	Compute the phase angle shift of indirect wave return relative to direct wave return when indirect path includes specular reflection in both directions.
MPATH1	13-6: Reflection Coefficients (Land)	Compute the land reflection coefficients based on user-chosen land form/cover.
MPATH1	13-7: Reflection Coefficients (Sea)	Compute the sea reflection coefficients based on user-chosen sea state.
RGIO	13-8: Surface Reflectivity	Compute the near and far surface reflection coefficients defined by user when using the numerical clutter model.

2.13.3 Desk Check Activities and Results

The code implementing this FE was manually examined using the procedures described in Section 1.1 of this report. Discrepancies found by desk checking are described in the following Table 2.13-3.

TABLE 2.13-3. Desk Checking Discrepancies.

Design Element	Desk Check Result
13-6: Reflection Coefficients (Land)	D1: PD^3 Equation [2.3-12] describes the surface reflection coefficient for land. In the *RADGUNS* code, however, 4 reflection coefficient values stored in the variable MPTABL array are used in an interpolation scheme to calculate the final reflection coefficient value. This does not appear to yield a savings in run time compared to use of Equation [2.3-12]. Furthermore, the effect on radar detection performance introduced by the approximations is unknown.
13-6: Reflection Coefficients (Land)	D2: The user-defined integers for land form and cover choice are not checked in *RADGUNS* for being within the allowed range of input values. Those integers are used during execution as array pointers in MPATH1 variables CVRTBL and FRMTBL. If incorrect integers are entered in the input file, array bounds are exceeded, and incorrect data are initialized while using the DESCRIPTIVE clutter/ multipath model. In contrast, the NUMERICAL model checks (and limits, if necessary) user inputs of the near- and far-surface reflection coefficients to ensure that they are in the range between 0.0 and 1.0.

TABLE 2.13-3. Desk Checking Discrepancies. (Contd.)

Design Element	Desk Check Result
13-7: Reflection Coefficients (Sea)	D3: The sea environment has many allowable sea states. The reflection coefficient for the sea, however, is independent of sea state. No independent reference was found that supports assigning a single reflection coefficient for all sea conditions.
13-8: Surface Reflectivity	D4: No calculations of reflection coefficients occur for the numerical ground clutter/multipath model. The values of near- and far-field surface reflection coefficients simply are read from the user input file. No independent reference was found for explanation of the conditions for which this simplified model (2 ground patches) should be used.

Internal documentation and code quality problems are characterized in Table 2.13-4.

TABLE 2.13-4. Code Quality and Internal Documentation Results.

Module	Code Quality	Internal Documentation
MPATH1, MPATH2	Overall code quality is good.	Internal documentation is accurate and basically adequate, although some enhancements would be helpful. The name of the individual(s) who wrote a subroutine, or a current, knowledgeable point of contact for information about each subroutine would be a useful improvement to the header. Additional descriptive comment interspersed within each subroutine would be useful to identify branching and other logic constructs. Definitions of all variables and constants with units of measure also would be useful. Furthermore, separation of the variable list by input, output, and local types would be helpful.

2.13.4 Software Test Cases and Results

Software testing was performed by running the entire *RADGUNS* model with instrumented code in the multipath subroutines (i.e., with “WRITE” statements inserted to print out variable values). One emphasis of multipath testing was model runs using all available user inputs. All user-defined and AAA system-specific input parameters were verified for correct initialization or passing to the subroutine of interest. This was accomplished by writing all such data at the beginning of a subroutine to the run summary file generated for each model run. Another emphasis was verification of intermediate calculations and initialization of system-specific parameters. These were also written to the instrumented run summary. Finally, an attempt was made to execute all lines of code related to multipath. Each execution branch had a write statement inserted at the end to record its completion; a tally of all branches recorded as executed identified code portions which never were executed. The user input parameter file allows the choice of two clutter/multipath models. These are the Descriptive (entered as DESC) and Numerical (NUME) Models. PD[3] Table 2.2.2.3-5 lists the options available to the user for the two models.

Multipath effects are associated primarily with a low incidence angle (with respect to the horizontal plane at the AAA system) between the threat and its target. Only one lowaltitude linear flight path was necessary for all tests; it was chosen to produce low incidence angles of reflected radar signals off the ground. The following initial conditions were not changed throughout multipath testing:

Parameter	Setting
Acquisition Type	Search Radar
Antenna Search Pattern	Sector
Center of Search	Target Azimuth, 0 deg Elev. angle
Azimuth Scan Rate	20 deg/sec
Sector Search Width	30 deg
Simulation Termination	10 sec of simulated target flight
Flight Path	Linear

The linear flight path parameters used were:

Parameter	X	Y	Z
Initial Position (m)	8000	0	500
Initial Velocity (m/s)		0	0
Initial Acceleration m/s^2	0	0	0

The linear flight path was along the x-axis, with the target flying in the direction of the radar. Optional features such as jamming, MTI, and target masking were not used; guns were disabled. Unless otherwise indicated, the standard *RADGUNS* system data were used for all test cases.

The test case descriptions in Table 2.13-5 below first provide the design element to be addressed, followed by the procedural steps used in each case. The numbered test procedures are designed to verify top-level variables. In general, three main steps occur sequentially: ensuring correct initialization of variables; examination of intermediate calculations and comparison with independent calculations; and final verification of the top-level variables.

The DESCRIPTIVE multipath model requires the user to pick either a land or a sea environment. The following environment for Tests 13-1 through 13-5 was chosen for simplicity: descriptive land environment with level land form and barren land cover. Tests for various other environments are covered in the remaining tests.

TABLE 2.13-5. Multipath Test Cases.

Test Case ID	Test Case Description
13-1	OBJECTIVE: Test Design Element 13-1, multipath factor, calculated in variable FMPATH in function MPATH2. PROCEDURE: 1. Run RADGUNS and observe initialization of GTARG, GMPATH, COSP2, COS2P2, TARRG, MPPAR(1), MPPAR(2), MPPAR(3), and MPPAR(4). 2. examine the value returned from Function RANDOM. 3. examine variables COEF, TEMP1, TEMP2. 4. Examine variable FMPATH. 5. Examine the value of Function MPATH2. 6. Re-run RADGUNS, and deposit a value of 1.5 in variable COEF after its first determination, and deposit a value of -1.0 in variable FMPATH after its first determination. Verify: 1. The value observed in Step 2 is within the range [-1,1]. 2. The value observed in Step 4 matches independent calculations of ASP-II Equation [2.13-5], utilizing the intermediate calculations observed in Step 3. 3. The value observed in Step 4 equals that of Step 5. 4. The value deposited in COEF in Step 6 is subsequently set equal to 1. 5. The value deposited in FMPATH in Step 6 is subsequently set equal to 0. Result: OK
13-2	OBJECTIVE: Test Design Element 13-2, Indirect Path Length, calculated in variable MPDIST in subroutine MPATH1. PROCEDURE: 1. Run RADGUNS and observe initialization of HANT, TARRG, ZTARG. 2. Examine HTARG and compare with independent calculation. 3. Examine MPDIST and compare with independent calculation. VERIFY: 1. Compare value observed in Step 2 with independent calculation of HANT +ZTARG (observed in Step 1). 2. Examine MPDIST and compare with independent calculation using ASP-II Equation [2.13-6]. RESULT: OK

TABLE 2.13-5. Multipath Test Cases. (Contd.)

Test Case ID	Test Case Description
13-3	OBJECTIVE: Test Design Element 13-3, Grazing Angle at Ground Reflection Point, calculated in variable REFLEL in subroutine MPATH1. The intermediate value REFEL is the (negative) elevation angle of the reflection point with respect to the antenna. PROCEDURE: 1. Run RADGUNS and observe initialization of HANT, TARRG, ZTARG. 2. Examine HTARG and MPDIST. 3. Examine REFEL. 4. Examine REFLEL. VERIFY: 1. If (HANT + HTARG) is less than (MPDIST), compare REFEL with independent calculation of: REFEL = -SIN^{-1} ((HTARG + HANT)/MPDIST) Otherwise, compare REFEL with the constant value assigned of: REFEL = –90 degrees. 2. REFLEL equals the absolute value of REFEL. RESULT: OK
13-4	OBJECTIVE: Test Design Element 13-4, Phase Angle Shift for Single-Bounce Path, calculated in variable PHIMP in subroutine MPATH1. PROCEDURE: 1. Run RADGUNS and observe initialization of PI, TARRG, HANT, WLNTH. 2. Examine HTARG and MPDIST. 3. Examine PHIMP. VERIFY: 1. PHIMP matches independent calculation of ASP-II Equation [2.13-10] using the values observed in Step 2. RESULT: OK
13-5	OBJECTIVE: Test Design Element 13-5, Phase Angle Shift for Double-Bounce Path, calculated as two times variable PHIMP in subroutine MPATH1. PROCEDURE: 1. Run RADGUNS and examine PHIMP and COS2P2. VERIFY: 1. Value of COS2P2 matches independent calculation of the cosine of 2áPHIMP. RESULT: OK

TABLE 2.13-5. Multipath Test Cases. (Contd.)

<table>
<tr><th>Test Case ID</th><th>Test Case Description</th></tr>
<tr><td>13-6</td><td>OBJECTIVE: Test Design Element 13-6, Reflection Coefficients for Land. Five land forms and six land covers were tested. Land height standard deviation data are stored in the variable array FRMTBL, and land cover height standard deviation data are stored in the variable array CVRTBL. These variables are used in calculation of the final value of the reflection coefficient MPPAR calculated in subroutine MPATH1.

PROCEDURE:
1. Enter “DESC” as the ground clutter/multipath model, and “LAND” as the type of environment in the user input file.
2. Enter “1” for land form and “1” for land cover in the user input file.
3. Execute RADGUNS.
4. Observe initialization of LNDFRM, LNDCVR, CVRTBL, FRMTBL, WLNTH.
5. Examine SIGMA.
6. Examine MPPAR(1) and MPPAR(2).
7. Repeat steps 2 through 6 using the following land form/cover combinations in Step 2 (five additional simulation runs total):
<table><tr><th>Land Form</th><th>Land Cover</th></tr><tr><td>2</td><td>2</td></tr><tr><td>3</td><td>3</td></tr><tr><td>4</td><td>4</td></tr><tr><td>5</td><td>5</td></tr><tr><td>5</td><td>6</td></tr></table>
VERIFY:
1. The value of SIGMA observed in Step 5 matches independent calculation of ASP-II Equation [2.13-13].
2. The value of MPPAR(1) observed in Step 6 matches independent calculations of the interpolated surface reflection coefficient.
3. The value of MPPAR(2) observed in Step 6 equals that of MPPAR(1).

RESULT: PD^3 Equation [2.3-12] describes the surface reflection coefficients for land. In the RADGUNS code, however, four reflection coefficient values stored in the variable MPTABL array are used in an interpolation scheme to calculate the final reflection coefficient value. This does not appear to yield a savings in run time compared to use of Equation [2.3-12]. Furthermore, the effect on radar detection performance introduced by the approximations is unknown.

The user-defined integers for land form and cover choice are <u>not</u> checked in RADGUNS for being within the range of allowed input values. Those integers are used during execution as array pointers in MPATH1 variables CVRTBL and FRMTBL. If incorrect integers are entered in the input file, array bounds are exceeded, and incorrect data are initialized while using the DESCRIPTIVE clutter/multipath model. In contrast, the NUMERICAL model checks (and limits if necessary) user inputs of the near- and far-surface reflection coefficients to ensure that they are in the range between 0.0 and 1.0.</td></tr>
</table>

TABLE 2.13-5. Multipath Test Cases. (Contd.)

Test Case ID	Test Case Description
13-7	OBJECTIVE: Test Design Element 13-7, Reflection Coefficients for Sea. Eight Sea States are available. The sea state, however, does not affect multipath calculations; only the fact of choosing a sea environment influences the reflection coefficients. PROCEDURE: 1. Input "DESC" as the ground clutter/multipath model, and "SEA" as the type of environment. 2. Enter "1" for the sea state and enter "0" for wind aspect angle. 3. Execute RADGUNS. 4. Observe the initialization of POLRZ. 5. Examine MPPAR(1) and MPPAR(2). 6. Repeat steps 2 through 5 using the sea state entries of 2,3,4,5,6,7,8 in Step 2 (seven additional simulation runs total). VERIFY: 1. MPPAR(1) is assigned a value in subroutine MPATH1 that is consistent with the polarization observed in variable POLRZ in Step 4. 2. The value of MPPAR(2) equals that of MPPAR(1). RESULT: One execution branch was not accessible in tests for the AAA system under investigation. The two branches available to calculate reflection coefficients for a sea environment are associated with different radar polarizations. The subject radar operates at only one polarization. This is not a discrepancy; it is noted here only for completeness.
13-8	OBJECTIVE: Test Design Element 13-8, Surface Reflectivity. The surface reflection coefficients are not calculated when the numerical clutter model is used. They simply are defined by the user and initialized in array variable MPPAR, Subroutine INPUT1. PROCEDURE: 1. Input "NUME" as the ground clutter/multipath model in the user input file. 2. Enter "0.00001" for both near and far surface reflection coefficients in the user input file. 3. Execute RADGUNS. 4. Enter "0.1" for both near and far surface reflection coefficients in the user input file. 5. Execute RADGUNS. VERIFY: 1. Multipath calculations are bypassed in Step 3. 2. Initialization of MPPAR(1), MPPAR(2), MPPAR(3), MPPAR(4) occur in Step 5. RESULT: OK

Numerical values (in an array) corresponding to each land form and cover are directly coded in the FORTRAN subroutines. Table 2.3-1 of the PD[3] presents numerical values for land form data that were tested for correct usage in *RADGUNS*. PD[3] Table 2.3-2 presents numerical values for land cover data that also were tested for correct usage. These values were written to an output file to record values as they arrived in the subroutine (MPATH1).

2.13.5 Conclusions and Recommendations

2.13.5.1 Code Discrepancies

From the verification results described in previous sections, the code for the multipath FE basically is a correct implementation of the design specified in the PD[3]. Minor discrepancies discovered during verification yield the following recommendations:

2.13.5.2 Code Quality and Internal Documentation

The developer should review all methods for calculating the surface reflection coefficients.

All user inputs should be checked to ensure values are within appropriate bounds.

It would be helpful to bring internal code documentation to a standardized format with more information about variable definitions and logical constructs.

The variables HANT and HTARG were called HA and HT in Version 1.7. The HTARG variable definition (as a comment statement) in subroutine MPATH1 was not changed from HT in Version 1.7 to HTARG in Version 1.8. This definition should be corrected in the current version.

2.13.5.3 External Documentation

The external documentation of multipath modeling in RADGUNS is good. Appendix VI of the combined user's/analyst's/programmer's manual presents a detailed analytical discussion of the multipath phenomena. The appendix also defines the subroutines which implement the multipath model. No additions to the documentation are recommended.